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Precipitation and Fire Impacts on Small Mammals in Shortgrass Prairie

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ABSTRACT The southern Great Plains and the northern part of the Texas Panhandle have received less attention from a biological perspective than other parts of the state. Although there is substantial information on the effects of fire on small mammals in the tallgrass and mixed-grass prairies, there is a lack of understanding of fire influences in the shortgrass prairie, specifically on small mammals. We conducted our study on the Cross Bar Cooperative Management Area (CMA), a 4,856 ha shortgrass prairie within the Texas panhandle. Our objective was to determine the effect of three different fire return frequencies and precipitation on diversity of the small mammal community. We sampled small mammals at Cross Bar CMA from 2004–2009 using a randomized block design that consisted of three blocks and nine separate plots. Plots were exposed to two fire treatments during the growing season; 2-year fire return, 4-year fire return, and 10-year non-burned control. We captured 835 individuals of 15 species of small mammals during 17,010 trap nights. Abundance and biomass of all small mammal species was positively related to the amount of precipitation recorded during the previous dormant season regardless of burning treatments. However, some species appeared to positively respond to burn treatment during the years of highest precipitation.

KEY WORDS Great Plains, prescribed fire, rodents, shortgrass prairie, small mammals, Texas panhandle, variable precipitation

The Great Plains extend from Canada to Mexico and once consisted of the tallgrass, mixed grass, and shortgrass plains. Native prairies were the largest vegetation group in North America and the remaining North American prairies are among the continent's most endangered ecosystems (Sampson and Knopf 1994, Rickletts et al. 1999). Since European settlement and the introduction of agriculture to North America, the distribution of native prairies has declined. In fact, the shortgrass prairie has decreased from 20% in Wyoming to 85% in Saskatchewan (Sampson and Knopf 1994). The decline in native prairie has become an ecological concern and recently the ecological value of shortgrass prairies for conservation of the prairie dog (*Cynomys* spp.) and burrowing owl (*Athene cunicularia*) have become apparent (Miller et al. 1994).

Natural wildfires influenced grasslands long before the arrival of humans (Kaufman et al. 1990, Brockway et al. 2002) and were important in the growth and evolution of the North American prairies by maintaining low levels of succession. Livestock ranching and human settlement led to formation of fire suppression programs in the 1950s and have altered the natural fire regime on grasslands by nearly eliminating fire as an ecological process (Archer 1989). The diminished presence of fire in these ecosystems is believed to be responsible for shifts in the composition, structure, and diversity of grasslands, leading specifically to the rise of invasive species and invasion by less fire-tolerant species (Wright 1974, D'Antonio 2000). Although there is debate over the accuracy of historical accounts of grasslands, it is generally accepted that as a result of poor management, woodlands and shrublands have begun to encroach on the Great Plains' prairies (Archer 1989). Additionally, the abundance of woody plants has increased substantially in grasslands worldwide (Bragg and Hulbert 1976, Briggs et al. 2002). Fire maintains the structure of prairies by suppressing woody vegetation (McPherson 1995, Briggs et al. 2002). Changes in biotic habitat components (e.g., herbaceous vegetation, shrubs, and woody debris) following fires have been shown to influence the abundance of small mammal populations within the prairies (Bock and Bock 1983, Converse et al. 2006).

Small mammal communities are highly variable in North American grasslands, and changes in the small mammal community are tied to changes in vegetation structure (Grant et al. 1977, Zwolak et al. 2012). Hence, differences in vegetation density can reflect the diversity of abiotic and biotic variables. For example, regions with highest density of small mammals tend to have higher, and more stable, mean annual precipitation (Grant and Birney 1979). Therefore, small mammal populations may serve as ecological indicators for prairie ecosystems. Small mammals are directly dependent on vegetation resources for food and cover and productivity may reflect vegetation availability (Ostfeld 1985, Zwolak et al. 2012) because changes in small mammal communities are frequently a response to shifts in grassland plant composition and habitat structure (Schweiger et al. 2000). Additionally, because only about 20% of original shortgrass prairie in North America remains today, the potential for grassland species extinction is of concern (Sampson and Knopf 1994). Changes in the habitat structure resulting from encroaching woody plants has potential to change the distribution, abundance, and occurrence of many small mammal species in prairies (M'Closkey and Lajoie 1975, Swihart and Slade 1990, Sietman et al. 1994, Horncastle et al. 2005).

Rainfall may indirectly effect small mammal productivity

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or directly affect the physiological tolerance of the animals (Wright 1983). More productive sites and years with higher, and more consistent, precipitation may promote higher densities and richness of vertebrates, including small mammals. Semiarid environments are especially variable in environmental conditions (Coupland 1958), and rainfall is arguably the principal cause of the vegetative variability within semiarid grassland environments (Bailey 1979, Wright and Bailey 1980, Lauenroth and Sala 1992, Weddell 1996, Oesterheld et al. 2001). Often, variation in annual production can be better explained by the sum of precipitation from the current and previous year than by any one year because of the carry-over of production potential from the previous year (Webb et al. 1978, Smoliak 1986). Lag effects are common in grasslands because of the close relationships between seed production and the dynamics of the entire community (Oesterheld et al. 2001).

The influence of prescribed burning in shortgrass prairies in not well understood, there is a need for more research on the effects of fire to achieve management objectives (Brockway et al. 2002). Although the importance of fire in grasslands is evident, there remains uncertainty in methods needed by land managers to restore fire to the grasslands that have long gone unburned (Brockway et al. 2002). More specifically, the effects of fire on mammalian species in shortgrass prairies are not well understood and native shortgrass prairie is understudied because of declines in this grassland type (Samson and Knopf 1994, Ford and McPherson 1996). Therefore, using two different management-based fire return intervals and an unburned control, we assessed abundance, richness, and biomass of small mammal communities in a shortgrass prairie over seven years.

STUDY AREA

The Panhandle region of Texas is flat to gently rolling (Jones et al. 1988) with a semi-arid and continental climate with low and irregularly distributed summer precipitation between 35 to 48 cm per year (Hafsten 1961). Temperatures for the Llano Estacado ranged from an average low of 2.8º C to an average high of 27º C and varied greatly by season and day (Hafsten 1961) with May–August having the highest temperature and rainfall. Also, high winds are characteristic of this area with the annual average velocity estimated between 19.3 and 24.1 km per hour (Wendorf 1961).

We conducted our study on Cross Bar Cooperative Management Area (CMA), 16 km north of Amarillo, Potter County, Texas. The Cross Bar CMA is a 4,856 ha shortgrass prairie that is situated at the junction of the High Plains and Rolling Plains ecoregions. The High Plains cover most of the Texas Panhandle with the Rolling Plains occurring along the eastern boundary of the High Plains and along the Canadian River. Currently, this property is ungrazed but had a history of livestock use from 1932 until 1993. After 1993, about 25% of the land was still being grazed and all grazing was stopped by 1999 (P. Tanner, Bureau of Land Management, personal communication). Currently, the Cross Bar CMA is used for research purposes by the Bureau of Land Management and West Texas A&M University.

The dominant grasses in the Cross Bar CMA were buffalograss (*Buchloë dactyloides*) and blue grama (*Boutelous gracilis*). The woody plants common in this area are honey mesquite (*Prosopsis glandulosa*), sand sagebrush (*Artemisia filifolia*), four-wing saltbush (*Atriplex canescens*), white sage (*Ceratoides lanata*), yucca (*Yucca* spp.), and cactus such as plains pricklypear (*Oputina polyacantha*) and pencil cholla (*O. leptocaulis*). All plant scientific names conform to the Flora of the Great Plains (Berkley 1986).

The Cross Bar CMA, like many parts of the region, has been used extensively as grazing land and has a history of over grazing and fire suppression which has led to rapid mesquite, pencil cholla, and yucca invasion in many parts (Wright and Bailey 1982, Ford and McPherson 1996, R. Kazmaier, West Texas A&M University, personal communication). The CMA is representative of the remaining shortgrass prairie in the Rolling Plains ecoregion and along the Canadian border.

METHODS

Experimental Design

We divided the Cross Bar CMA into three treatments (e.g., 2-year fire return, 4-year fire return, and 10-year nonburned control) that were replicated three times for a total of nine experimental plots. We selected fire return intervals based on historic intervals (Samson and Knopf 1994, Ford and McPherson 1996). Additionally, we partitioned these treatments into three blocks to control for spatial variation and environmental conditions (e.g., topographic conditions). Burning was conducted by the BLM in accordance with our experimental design. We conducted 2-year burns in spring (Mar–Apr) of 2002 and 2003, 2005, 2007, and 2009. We burned four-year treatments in 2003 and 2007. The nine separate experimental plots were 120 ha in size, with each plot sampled using two small mammal transects.

Sampling Methods

In 2004, we began sampling small mammals two times per year within one week of prescribed burning. We conducted the growing-season sampling session between March and April and the dormant-season sampling session between September and November. We baited traps with oats and provided polyester bedding for thermal cover. Each sampling session consisted of a 2-week period over which nine transects were sampled. Trapping sessions lasted for three consecutive nights for a total of 1,620 trap nights per trapping session. Each transect had 15 stations spaced 15 m apart, sampled with two Sherman live traps (7.6 × 8.9 × 30.4 cm; HB Sherman Trap Company, Tallahassee, FL, USA) at each station, for a total of 18 transects and 540 small mammal live traps. We checked traps once each morning, and information recorded on each capture consisted of length of hind foot, ear, and tail. We recorded mass and sex of individuals for each capture and marked each animal by hair clipping a 1cm^2 patch on the rump (Skinner and Chimimba 2005). From October 2004 to March 2008, we ear-tagged and fur-clipped all small mammals captured. Following April 2008, small mammals were only fur-clipped because of time constraints.

From August 2002 to August 2009, we collected precipitation data on-site and averaged precipitation amounts between 6 rain gauges spread throughout the Cross Bar CMA. We divided precipitation and capture data into dormant season (Oct–Mar) and growing season (Apr–Sep) time periods.

Statistical Analysis

We compared mean abundance of all species combined, biomass, and richness with year, season, and frequency of burning (treatment) as main effects in a repeated measures analysis of variance (ANOVA; SAS Institute, Cary, North Carolina, USA). In all cases, we considered the plot the experimental unit and a $P < 0.05$ ($\alpha = 0.05$) indicated that comparisons were statistically significant. We tested normality using Shapiro-Wilks w-statistic (Shapiro and Wilks 1965) and conducted mean separation tests using a protected least significant difference test (Carmer and Swanson 1971).

We defined abundance as the total number of animals of each species captured per transect and biomass as the total weight of all animals. During each sampling period, we averaged abundance for both transects within a sampling plot. We averaged fall abundance within each burn plot for the dormant seasons. We examined the relationship between abundance and biomass of small mammals to precipitation levels by plotting means along a regression curve (SigmaPlot 8.0; Systat Software Inc., Richmond, CA, USA).

RESULTS

Small Mammal Community

Throughout the study, we captured 835 individuals of 15 species of small mammals during 17,010 trap-nights. Species captured included the hispid cotton rat (*Sigmodon hispidus*; n = 158), white-footed mouse (*Peromyscus leucopus*; n = 156), plains harvest mouse (*Reithrodontomys montanus*; n = 124), hispid pocket mouse (*Chaetodipus hispidus*; n = 112), northern grasshopper mouse (*Onychomys leucogaster*; n = 86), southern plains woodrat (*Neotoma micropus*; n = 76), northern pygmy mouse (*Baiomys taylori*; n = 43), western harvest mouse (*Reithrodontomys megalotis*; n = 24), silky pocket mouse (*Perognathus flavus*; n = 22), deer mouse (*P. maniculatus*; n = 21), Ord's kangaroo rat (*Dipodomys ordii*; n = 5), thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*; n = 3), spotted ground squirrel (*S. spilosoma*; n = 2), house mouse (*Mus musculus*; n = 2), and white-toothed woodrat (*N. leucodon*; n = 1).

Precipitation

Rainfall was highest in the dormant season of 2004 at 42.84 cm and lowest in the growing season of 2006 at 0.00

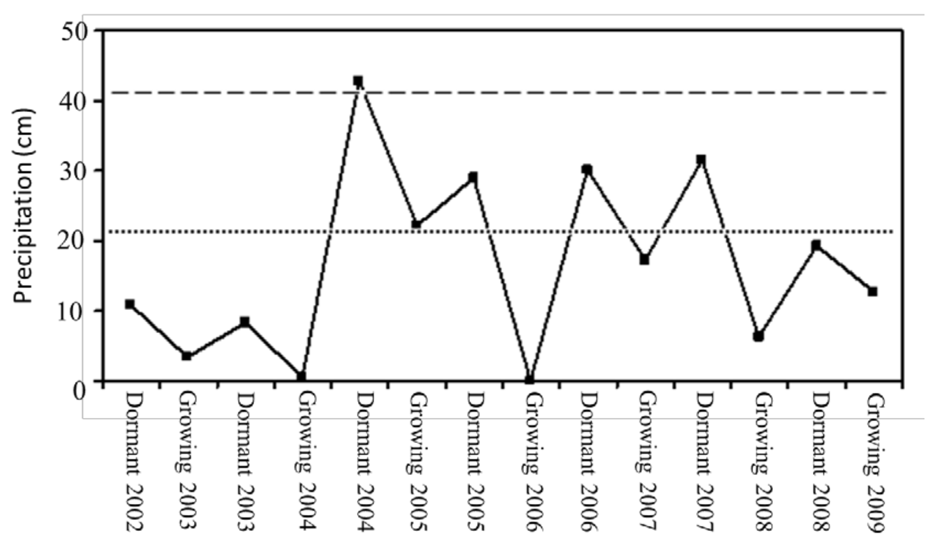

Figure 1. Total precipitation (cm; solid line) and average annual precipitation (cm; dotted line) recorded on the Cross Bar Cooperative Management Area and the average precipitation for the Llano Estacado (cm; dashed line) Potter County, Texas, USA, fall 2002–spring 2009.

cm. Average annual rainfall over the course of the study (fall 2004–fall 2009) was 20.87 cm, which was 50% lower than the long-term rainfall average for the Llano Estacado (Fig. 1).

Response to Season, Year, and Fire Frequency

Species Richness.—Species richness was affected by year ($F_{2, 5}$ = 6.18, P < 0.001; Table 1) and season ($F_{2, 1}$ = 13.36, P = 0.001). Richness was greatest in 2005 and higher during the growing (4.12, SE = 0.3) than the dormant season (2.72, SE = 0.3). Richness exhibited a significant year*season interaction ($F_{2, 8}$ = 10.50, P < 0.001; Table 2) with highest richness in the dormant season of 2005 followed by the growing seasons of 2008 and 2005. Species richness was not affected by treatment ($F_{2, 2}$ = 0.46, P = 0.634; Table 3) and there was not an interaction of treatment*year ($F_{2, 10}$ = 0.48, P = 0.90; Table 4), treatment*season ($F_{2, 4}$ = 1.48, P = 0.221; Table 5), or treatment*year*season ($F_{2, 16}$= 1.34, P = 0.208).

Total Abundance.—Total small mammal abundance was affected by a year*season interaction ($F_{2, 8}$ = 8.32, P < 0.001; Table 2), with total abundance higher in the dormant season of 2005 compared to all other years. Total fall abundance during the 3 highest precipitation events (fall 2004, fall 2006, and fall 2008) exceeded total abundance from the 3 lowest precipitation events (dormant seasons of 2004, 2006, and

Table 1. Mean species richness, abundance, and biomass of small mammals (per 100 trap nights) on the Cross Bar CMA Potter County, Texas, USA, 2004–2009. Means averaged across years followed by the same letter are similar (α = 0.05).

Year	Species Richness $\bar{X} \pm$ SE	Total Biomass $\bar{X} \pm$ SE	Total Abundance $\bar{X} \pm$ SE
2004	2.00 ± 0.37[a]	205.25 ± 80.89[a]	2.22 ± 0.63[a]
2005	5.22 ± 0.53[c]	396.05 ± 112.49[b]	9.55 ± 1.91[b]
2006	2.67 ± 0.44[a]	195.90 ± 49.95[a]	3.23 ± 0.46[a]
2007	3.78 ± 0.41[cb]	147.67 ± 52.52[a]	3.58 ± 0.46[a]
2008	3.11 ± 0.52[ab]	115.85 ± 20.42[a]	3.80 ± 0.77[a]
2009	2.61 ± 0.35[a]	83.36 ± 22.75[a]	2.99 ± 0.71[a]

Table 2. Mean species richness, abundance, and biomass of small mammals (individuals per 100 trap nights) during growing (Apr–Sep) and dormant (Oct–Mar) seasons on the Cross Bar CMA, Potter County, Texas, USA, 2004–2009. Means averaged across year and season followed by the same letter are similar (α = 0.05).

Year	Species Richness $\bar{X} \pm$ SE	Species Biomass $\bar{X} \pm$ SE	Species Abundance $\bar{X} \pm$ SE
2004			
Dormant	2.00 ± 0.37[a]	205.25 ± 80.89[ac]	2.22 ± 0.63[ad]
2005			
Growing	4.44 ± 0.78[cd]	225.25 ± 79.52[ac]	6.30 ± 1.42[c]
Dormant	6.00 ± 0.65[b]	566.85 ± 200.40[b]	12.80 ± 3.28[b]
2006			
Growing	3.78 ± 0.43[c]	330.26 ± 72.94[c]	5.07 ± 0.47[dc]
Dormant	1.56 ± 0.58[a]	61.53 ± 27.74[a]	1.38 ± 0.58[ae]
2007			
Dormant	3.78 ± 0.40[c]	147.67 ± 52.52[ac]	3.58 ± 0.46[a]
2008			
Growing	5.00 ± 0.41[bd]	172.68 ± 21.41[ac]	6.68 ± 0.63[c]
Dormant	1.22 ± 0.32[a]	59.03 ± 22.50[a]	0.93 ± 0.28[a]
2009			
Growing	3.44 ± 0.48[c]	111.97 ± 38.14[a]	4.75 ± 1.12[ceg]
Dormant	1.78 ± 0.36[a]	54.75 ± 23.26[a]	1.24 ± 0.29[a]

Table 3. Mean species richness, abundance, and biomass of small mammals (number per 100 trap nights) sampled in 3 burn treatments (2-, 4-, and 10-year fire return interval) on the Cross Bar CMA, Potter County, Texas, USA, 2004–2009. Means averaged across burn treatment followed by the same letter are similar (α = 0.05).

Treatment	Species Richness $\bar{X} \pm$ SE	Total Biomass $\bar{X} \pm$ SE	Total Abundance $\bar{X} \pm$ SE
2–year burn	3.03 ± 0.36[a]	131.89 ± 24.54[a]	3.68 ± 0.62[a]
4–year burn	3.43 ± 0.39[a]	198.44 ± 57.55[a]	4.40 ± 1.10[a]
10–year burn	3.43 ± 0.40[a]	250.25 ± 57.97[a]	5.40 ± 0.93[a]

Table 4. Mean species richness, abundance, and biomass of small mammals (individuals per 100 trap nights) in 3 burn treatments (2-, 4-, and 10-year fire return interval) on the Cross Bar CMA Potter County, Texas, USA, 2004–2009. Means averaged across year and burn treatment followed by the same letter are similar (α = 0.05).

Year	Species Richness $\bar{X} \pm$ SE	Species Biomass $\bar{X} \pm$ SE	Species Abundance $\bar{X} \pm$ SE
2004			
2–year burn	2.00 ± 0.58[a]	218.67 ± 133.00[a]	2.41 ± 0.98[a]
4–year burn	1.67 ± 0.67[a]	173.33 ± 158.33[a]	1.67 ± 1.11[a]
10–year burn	2.33 ± 0.88[a]	223.75 ± 187.03[a]	2.59 ± 1.52[a]
2005			
2–year burn	4.33 ± 0.76[a]	221.25 ± 81.82[a]	7.29 ± 1.92[a]
4–year burn	5.33 ± 1.20[a]	421.96 ± 263.09[a]	9.23 ± 4.97[a]
10–year burn	6.00 ± 0.73[a]	544.55 ± 206.22[a]	12.13 ± 2.50[a]
2006			
2–year burn	3.00 ± 1.00[a]	164.42 ± 71.55[a]	2.96 ± 0.99[a]
4–year burn	2.83 ± 0.54[a]	144.22 ± 59.27[a]	3.41 ± 0.80[a]
10–year burn	2.17 ± 0.79[a]	279.05 ± 121.24[a]	3.30 ± 1.32[a]
2007			
2–year burn	3.33 ± 0.33[a]	59.79 ± 25.56[a]	3.34 ± 0.56[a]
4–year burn	3.67 ± 0.88[a]	183.71 ± 92.22[a]	3.15 ± 1.13[a]
10–year burn	4.33 ± 0.88[a]	199.52 ± 134.49[a]	4.26 ± 0.74[a]
2008			
2–year burn	3.00 ± 1.13[a]	101.04 ± 35.12[a]	3.72 ± 1.55[a]
4–year burn	3.67 ± 0.88[a]	139.65 ± 44.88[a]	4.08 ± 1.42[a]
10–year burn	2.67 ± 0.80[a]	106.88 ± 28.82[a]	3.61 ± 1.29[a]
2009			
2–year burn	2.17 ± 0.48[a]	33.13 ± 6.25[a]	1.58 ± 0.44[a]
4–year burn	2.67 ± 0.67[a]	107.83 ± 40.03[a]	2.87 ± 0.92[a]
10–year burn	3.00 ± 0.73	109.13 ± 53.69[a]	4.54 ± 1.78[a]

2008) by 39.13 captures per 100 trap nights (range = dry: 7.59 to wet: 52.15). Total small mammal abundance was not affected by burn treatment ($F_{2,2} = 0.86$, $P = 0.43$; Table 3) or season (growing: 5.7, SE = 0.5, dormant: 3.69, SE = 0.8; $F_{2,1} = 2.48$, $P = 0.12$; Table 1) or any interactions ($F_{2,16} \geq 0.31$, $P \geq 0.27$; Tables 4, 5).

Total Biomass.—Total small mammal biomass was effected by a year*season interaction ($F_{2,8} = 4.70$, $P = 0.001$; Table 2) with total biomass higher in the dormant season of 2005 than any other season. Total fall biomass per 100 trap nights was averaged within each burn treatment and the total small mammal biomass per 100 trap nights from the three

Table 5. Means of species richness, abundance, and biomass of small mammals (individuals per 100 trap nights) sampled in 3 burn treatments and averaged across Growing (Apr–Sep) and Dormant (Oct–Mar) season and burn treatment (2-, 4-, and 10-year fire return interval). Cross Bar CMA Potter County, Texas, USA, 2004–2009. Means followed by the same letter are similar (α = 0.05).

Year	Species Richness $\bar{X} \pm$ SE	Species Biomass $\bar{X} \pm$ SE	Species Abundance $\bar{X} \pm$ SE
Growing			
2–year burn	3.92 ± 0.40[a]	139.23 ± 35.62[a]	4.41 ± 0.65[a]
4–year burn	3.83 ± 0.51[a]	191.54 ± 42.61[a]	5.06 ± 0.67[a]
10–year burn	4.75 ± 0.54[a]	299.36 ± 69.64[a]	7.64 ± 0.95[a]
Dormant			
2–year burn	2.44 ± 0.50[a]	127.00 ± 40.07[a]	3.20 ± 0.94[a]
4–year burn	3.17 ± 0.56[a]	203.03 ± 92.90[a]	3.96 ± 1.79[a]
10–year burn	2.56 ± 0.47[a]	217.51 ± 85.47[a]	3.91 ± 1.32[a]

highest precipitation events (fall 2004, fall 2006, and fall 2008) exceeded total biomass from the three lowest precipitation events (dormant seasons of 2004, 2006, and 2008) by 2,242.21 grams (Range = dry: 915.89 to wet: 3,158.10). Total small mammal biomass was not affected by treatment ($F_{2, 2}$ = 1.40, P = 0.254; Table 3) or season (growing: 210.04, SE = 33, dormant: 182.51, SE = 43.7; $F_{2, 1}$ = 0.18, P = 0.671) or any interactions ($F_{2, 16} \geq 0.38$, $P \geq 0.34$; Table 5).

Response to Precipitation

Total Abundance and Biomass.—A positive relationship between precipitation and abundance of all small mammals was detected, and changes in precipitation explained 96–98% of the change in abundance of all small mammals (2-year fire return: R^2 = 0.97, P = 0.02; 4-year fire return: R^2 = 0.98, P = 0.01; 10-year nonburned control: R^2 = 0.96, P = 0.02; Fig. 2A). Variation in precipitation explained between 94 and 97% of the change in biomass of all small mammals in the 4-year and nonburned plots (2-year fire return: R^2 = 0.78, P = 0.13; 4-year fire return: R^2 = 0.94, P = 0.04; 10-year nonburned control: R^2 = 0.97, P = 0.02; Fig. 2B).

DISCUSSION

Small Mammal Community and Precipitation

Effects of fire on the short grass prairie ecosystem is thought to be minor compared to short term climate changes, especially because the principal natural disturbance in the central Great Plains is drought (Albertson and Tomanek 1965, Wright and Bailey 1980). For example, on the Cross Bar CMA, periods of increased precipitation in fall 2004, resulted in an increase in capture success in the dormant season of 2005. Capture success during the dormant season of 2005 was 13.8 times greater than capture success during the dormant season of 2008, which followed a prolonged drought. Additionally, abundance of small mammals declined from fall 2005 to spring 2009 with decreasing precipitation over this period. Additionally, we detected a time lag between the onset of drought and population decline as small mammal abundance decreased by over half in as little as 6 months as a result of drought in 2005.

Unlike much of the current research which has detected a response of small mammal communities to fire (Clark and Kaufman 1990, Zwolak 2009, Fontaine and Kennedy 2012, Raybuck et al. 2012) we did not observe the same results. Instead, for most species there were no differences in total small mammal captures between burn plots, suggesting that prescribed fire had little effect on the small mammal community (Bock and Bock 1978, Ford et al. 1999, Fitzgerald et al. 2001). However, similar to Fitzgerald et al. (2001), a few species varied across treatments, but this was only apparent in the years that received the highest levels of precipitation. Inferences from Fitzgerald et al. (2001) are limited, though, because of lack of replication and long-term monitoring. However, our results support previous observations that immediate impacts of fire in the shortgrass community do not include a reduction in overall small mammal abundance.

Species Richness.—Small mammal species richness decreased following periods of drought but remained high following periods of average precipitation. Reed et al. (2006) determined that an increase in forage productivity as a result of precipitation increased richness of herbivorous and insectivorous small mammal species, which comprised the largest component of the community on the Cross Bar CMA. Similarly, productivity and richness has been observed in rodents in several arid environments (Owen 1990, Laurenroth and Sala 1992, Briggs and Knapp 1995).

Total Abundance and Biomass.—Little information has been reported on the effects of burning on small mammals of the shortgrass prairie. Consequently, we are forced to make comparisons to other prairie grassland systems. However, comparisons are difficult because semi-arid systems, and

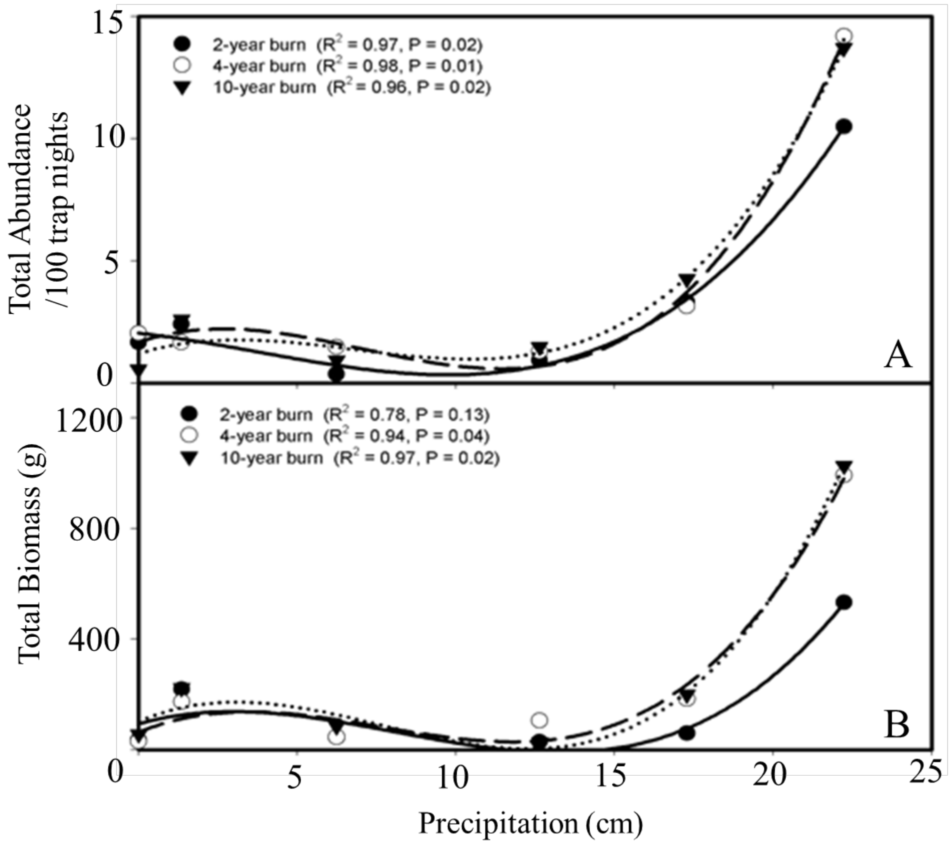

Figure 2. Relationship between previous dormant season precipitation and fall abundance (A) and biomass (B) of all small mammals in 2-, 4-, and 10-year burn plots on the Cross Bar CMA, Potter County, Texas, USA, 2004–2009. Arrows represent periods where burning took place.

the small mammal community on the Cross Bar CMA, are driven primarily by precipitation events. Regardless of burn treatment (which is frequently not the case in more temperate grassland systems), total abundance and biomass of small mammals was significantly higher ($P \leq 0.05$) following years of highest precipitation relative to all other years during the study. For example, Layne (1974), determined that rodents disappeared from flatwoods pine (*Pinus* spp.) habitat for two months following burns, and reappearance of small mammals to the area resulted from increased ground cover rather than an increase in precipitation events. In the shortgrass prairie, abundance of small mammals can shift from a single burn, but such changes are usually ephemeral (Knapp and Skinner 2009) because small mammal response is typically a response to vegetation production and availability, and is rarely tied to intensity of fire (Knapp and Skinner 2009).

The results of our research were consistent with the majority of studies on fire response of small mammals in semiarid environments (Letnic and Dickman 2010, Kelly et al. 2012). Furthermore, because a response was only detected following years of high precipitation, it is difficult to determine the specific response to burn treatment. The shortgrass prairie appears to be unique in its response to fire as a management practice because of the low density of small mammals and the habitat response to precipitation.

The shortgrass prairie evolved with fire as a vital and important component of the ecosystem. It is not surprising the small mammals of the prairie appear to be generally resilient to fire (Kaufman et al. 1988, Ford 2001). However, this resilience may not hold true for prairies in the future. Future climatic changes have the potential to affect productivity and alter the frequency and intensity of natural and/or management-related disturbances (Weddell 1996). Future research in the Southern Great Plains must aim to establish connections between climatic changes and changes in disturbance (precipitation and fire), especially because organisms are adapted to the disturbance regimes that are typical of the regions where they evolved (Weddell 1996).

MANAGEMENT IMPLICATIONS

Knowledge of small mammal response to fire and precipitation may allow resource managers to accurately predict effects prescribed burns will have on this ecosystem. If burning is necessary to maintain brush levels, a 4-year fire return appears to be a cost-effective and useful tool to reduce brush encroachment and increase biodiversity in an endangered ecosystem while keeping the small mammal fauna intact. Additionally, because climate drives changes in semi-arid systems, long term research on the effects of fire and fire frequency in the shortgrass prairie are needed to fully evaluate the role in the southern Great Plains.

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